

A Method and Apparatus for Assessing Performance of Optical Systems

[30020369 US]

Field of the Invention

- [0001] This invention relates to a method and apparatus for assessing performance of optical systems, and particularly, though not exclusively, to such a method and apparatus for accelerating assessment of performance using bit error rate (BER) tests.

Background of the Invention

- [0002] In an assessment of the performance of optical transmission systems, bit error rate (BER) tests are usually used. BER is defined as the ratio between the number of erroneously received bits to the total number of bits received over a period of time. In modern optical transmission systems, the BER test normally takes a long time to perform. For example, to evaluate a BER of 10^{-14} for data that is transmitted at a bit rate of 2.5 Gb/s, the measurement time needed is 12 hours. Performance of an optical system can also be defined by a parameter called Q-factor. The Q-factor indicates the signal-to-noise ratio of the signal and is defined as:

$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0}$$

- where μ_1 is the mean value of the "1's", μ_0 is the mean value of the "0's", σ_1 is the standard deviation of the level of "1's" and σ_0 is the standard deviation of the level of "0's". Q-factor measurement can greatly accelerate the test. Through reducing test time, the efficiency and benefit in cost and time can be obtained in design, manufacture, installation, maintenance and monitor of optical transmission systems.

- [0003] Several methods have been proposed to estimate the BER by calculation of the Q-factor. For example, one method disclosed in an article entitled "Margin Measurements in Optical Amplifier Systems" by Neal S. Bergano, F.W. Kerfoot and C.R. Davidson, published in IEEE Photonics Technology Letters, Vol. 5, No. 3, March 1993, adjusts the 'Decision Threshold' level of a tester's receiver away from the optimal value which gives the minimum BER. The shift of the decision threshold level increases the BER measured to a high level that is measurable in a short time. The measured high BER values

are then used to mathematically extrapolate to the BER at the optimal decision threshold.

[0004] Another known method is the 'Light Interference' method, which was described by P. Palacharla, J. Chrostowski and R. Neumann in a paper entitled 5 "Techniques for Accelerated Measurement of Low Bit Error Rates in Computer Data Links" published in the *Proceedings of the IEEE Fourteenth Annual International Phoenix Conference on Computers and Communications*, Scottsdale, AZ, March 28-31, 1995, pp.184-190. In this method, a sinusoidal interfering light source is coupled to the transmission data signal to increase the 10 BER measured at the receiver, allowing the high BER to be measured in a short time. Through the resultant Q-factor measurement, BER in the absence of the interference signal can then be extrapolated.

Brief Summary of the Invention

15 [0005] The present invention seeks to provide an alternative method and apparatus for accelerating assessment of performance using bit error rate (BER) tests, as compared to the prior art.

[0006] Accordingly, in a first aspect, the invention provides an apparatus for accelerating assessment of an optical transmission system using Bit Error Rate 20 (BER) tests, the apparatus comprising a controllable laser transmitter and a data generator coupled to the controllable laser transmitter for modulating the laser transmitter with transmission data, the controllable laser transmitter having an output coupled to an optical transmission system to be assessed, a BER measurement unit coupled to an output of the optical transmission system, a processing unit coupled to the BER measurement unit and to a laser controller 25 coupled to the controllable laser transmitter for adjusting the extinction ratio of the controllable laser transmitter to provide relatively high test BER values at the BER measurement unit, the processing unit including a calculator for calculating a Q-factor for at least two different values of the extinction ratio from the 30 relatively high measured test BER values and for obtaining a Q-factor value by extrapolation therefrom for an extinction ratio of the controllable laser transmitter in normal operation thereby enabling the BER to be calculated for normal operation of the controllable laser transmitter.

[0007] The controllable laser transmitter may be an electrically and directly modulated laser diode which outputs a digital light signal, the light output of the laser diode being modulated by the transmission data.

[0008] In one embodiment, the data generator may be a Pseudo Random Bit Sequence (PRBS) Generator.

[0009] The optical transmission system may include a forward error correct (FEC) element.

[0010] According to a second aspect, the invention provides a method for accelerating assessment of an optical transmission system using Bit Error Rate (BER) tests, the method comprising the steps of generating test data for modulating a laser transmitter, outputting light from the laser transmitter modulated by the test data, receiving the modulated light via an optical transmission system, measuring the BER for the received light, adjusting an extinction ratio of the laser transmitter to produce relatively high measured BER values, calculating a Q-factor for at least two different values of the extinction ratio from the measured BER values, obtaining a Q-factor by extrapolation therefrom for an extinction ratio of the laser transmitter in normal operation, and calculating the BER for normal operation of the laser transmitter.

[0011] The step of generating data may involve generating Pseudo Random Bit Sequence (PRBS) data. In one embodiment, the method may further comprise the step of forward error correction (FEC) in the optical transmission system prior to measurement of BER values.

[0012] The step of outputting light from the laser transmitter may comprise modulating the light output of a laser diode of the laser transmitter to provide a digital output light signal.

Brief Description of the Drawings

[0013] Two embodiments of the invention will now be more fully described, by way of example, with reference to the drawings, of which:

30 FIG. 1 shows, schematically, an apparatus according to a first embodiment of the present invention for accelerated assessment of an optical transmission system;

FIG. 2 shows, schematically, an apparatus according to a second embodiment of the present invention for accelerated assessment of an optical transmission system; and

5 FIG. 3 shows an example of Gaussian probability distribution of binary signals in optical transmission systems with two different extinction ratios.

Detailed Description of the Drawings

[0014] Thus, FIG. 3 shows, as an illustrative example, Gaussian probability distributions of binary signals in an optical transmission system for two different 10 extinction ratios of a laser transmitter. The continuous line shows the distributions of the average "0" level and the average "1" level at a higher extinction ratio and the dotted line shows the distributions at the lower extinction ratio. As can be seen, although the spacing of the "0" and "1" distributions has changed, so that they are much closer together at the lower extinction ratio, the 15 average power of the transmission data signal at the different extinction ratios is unchanged. Thus, without changing the average power of the optical transmission data signal nor the decision threshold of the receiver, there is still more area of overlap between the "1" and "0" probability distributions as the extinction ratio of the laser transmitter decreases. Therefore, the bit error rate 20 (BER) increases as the extinction ratio decreases, resulting in a higher BER to be measured.

[0015] Figure 1 shows an apparatus 10 for accelerated assessment of an optical transmission system 3. The apparatus includes a data pattern generator 1, which is coupled to a laser transmitter 2. The data pattern generator 1 25 outputs a pseudo random bit sequence (PRBS) of test data which is used to modulate the light output of the laser transmitter 2. The laser transmitter may include a laser diode, which is modulated by the test data. The modulated output of the laser transmitter (laser diode) 2 is inserted into the optical transmission system 3 under test. The output data signal from the optical 30 transmission system 3 is detected by a BER measurement unit 4. The measured BER values are passed to a control and processing module 6. The control and processing module 6 is used to control the operation of the whole test set and to process the received data for BER measurement and Q-factor calculation. In order to reduce the time taken for the BER measurements to be

carried out, a laser controller 5 is used to adjust the extinction ratio of light output from the laser transmitter 2. The control and processing module 6 thus controls the extinction ratio of the laser transmitter 2 and, from the BER values received from the BER measurement unit 4, and the associated extinction ratios, 5 determines a BER value for the system under optimum conditions.

[0016] The relationship between Q-factor and BER will now be explained. BER is defined by:

$$BER = p(1)P(0/1) + p(0)P(1/0) \quad (1)$$

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where $p(1)$, $p(0)$ and $P(1/0)$, $P(0/1)$ represent the probabilities and the conditional (Gaussian) probabilities of "1" level and "0" level signals, respectively.

[0017] For a Gaussian noise system, the conditional probabilities are 15 expressed as:

$$P(1/0) = \frac{1}{2} erfc\left(\frac{\mu_{th} - \mu_0}{\sqrt{2}\sigma_0}\right) \quad (2)$$

$$P(0/1) = \frac{1}{2} erfc\left(\frac{\mu_1 - \mu_{th}}{\sqrt{2}\sigma_1}\right) \quad (3)$$

20 where μ_1 and μ_0 represent the average power of "1" level, "0" level signals and μ_{th} represents the threshold level of the receiving decision circuit; σ_1 and σ_0 represent the root mean square (rms) noise level for the "1" level and "0" level signals, respectively, and $erfc$ is an error function.

[0018] Thus, BER can be expressed as:

$$25 \quad BER = \frac{1}{4} erfc\left(\frac{\mu_{th} - \mu_0}{\sqrt{2}\sigma_0}\right) + \frac{1}{4} erfc\left(\frac{\mu_1 - \mu_{th}}{\sqrt{2}\sigma_1}\right) \quad (4)$$

The minimum bit error rate (BER) occurs at an optimal threshold $\mu_{th-optimal}$, when the two terms in Equation (4) are equal, that is:

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$$\frac{\mu_{th} - \mu_0}{\sigma_0} = \frac{\mu_1 - \mu_{th}}{\sigma_1} = Q \quad (5)$$

[0019] Hence, BER can be expressed as:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) = \frac{1}{2} erfc\left[\frac{\sqrt{2}\mu_{avg}(r_{ER}-1)}{(\sigma_1 + \sigma_0)(r_{ER}+1)}\right] \quad (6)$$

where the Q-factor is defined as: $Q = (\mu_1 - \mu_0)/(\sigma_1 + \sigma_0)$, the average signal

5 power is defined as: $\mu_{avg} = (\mu_1 + \mu_0)/2$, and the extinction ratio of the signal is
defined as: $r_{ER} = \mu_1/\mu_0$. From Equation (6), it can be seen that the BER can be
mathematically expressed in terms of the extinction ratio of the signal.

[0020] Thus, in order to test the system to provide the BER for the system in
operation, the extinction ratio of the laser transmitter 2 is adjusted by the laser

10 controller 5 to a first low value so that the BER measured by the BER
measurement module is high. Thus, the measurement can take place in a
relatively short period of time. Using equation (6), the processing module 6 can
then calculate the Q-factor for that first extinction ratio value. The laser
controller then sets the extinction ratio to a second low value and the BER is
15 again measured and the Q-factor is calculated for that second extinction ratio
value. Thus, the Q-factor for much higher extinction ratio values can be
extrapolated from the Q-factor values at low extinction ratios. The processing
module 6 carries out the extrapolation to determine the Q-factor for operational
extinction ratio values and then calculates the BER. In this way, the optimum
20 extinction ratio to provide the lowest BER can be determined.

[0021] A second embodiment of the invention will now be described with
reference to FIG. 2, in which the same elements as those of FIG. 1 have the
same reference numbers. Again, a BER pattern generator 1 outputs a pseudo
random bit sequence (PRBS) transmission data signal to laser transmitter 2, the

25 laser diode of which outputs light modulated with PRBS transmission data into
an optical transmission system 7 which, in this case, includes a forward error
correct (FEC) element. The output data signal from the optical transmission
system 7 is detected by the BER measurement unit 4. The extinction ratio of
the light output of the laser transmitter 2 can be adjusted to result in high BER
30 values in the system under test. The control & processing module 6 is used to
control the work and operation of the whole test set and to process the received
data for BER measurement and Q-factor calculation and to extrapolate to

determine optimal BER. The accelerated BER testing through Q-factor measurement allows evaluation of how the FEC element corrects and improves the quality of the transmission data signal.

- [0022] Again, the extinction ratio values of the laser transmitter 2 are set so
5 as to generate a high BER after passing through the optical transmission
system 7. However, for an optical transmission system with an FEC element,
setting the second extinction ratio to a value different to the first extinction ratio
value may not provide a different BER measurement because the FEC element
corrects and improves the quality of the transmission data signal so that the
10 BER measurement may well be very similar for the second extinction ratio value
as for the first extinction ratio value. Thus, in this embodiment, the second
extinction ratio of the laser transmitter is adjusted continuously by the laser
controller 5 until the processing module 6 receives a measured BER that is
substantially different to the BER measured for the first extinction ratio value. In
15 this way, the relationship between the extinction ratio values and the Q-factor
can be properly determined so that the BER at the operational extinction ratio
values can be extrapolated.

- [0023] It will thus be apparent that the present invention can be used to
assess relatively quickly optical transmission systems having relatively low
20 operational BER.

- [0024] It will be appreciated that although only two particular embodiments of
the invention have been described in detail, various modifications and
improvements can be made by a person skilled in the art without departing from
the scope of the present invention. For example, the PRBS data from the BER
25 pattern generator can generate data signal for the assessment of various types
of optical transmission systems, such as SONET/SDH.